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Toward urban environmental sustainability: The carbon footprint of Foggia's municipality

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A B S T R A C T

Cities are mainly responsible for greenhouse gas (GHG) emissions in the atmosphere and thus for climate change. The European Union (EU) set up a series of strategies and policies to facilitate the elaboration of climate change mitigation and adaptation of urban plans. To do this, it is necessary to measure the city's GHG emission level. The Urban Carbon Footprint (UCF) and its derivation, the Relative Carbon Footprint (RCF), represent the most appropriate tools for obtaining this important information.

The present paper applies these indicators to a small city (150 000 inhabitants) located in Southern Italy, a novelty for academic studies, which usually concentrate on megacities. The study focuses only on CO_2 emissions, as these represent 90% of the total GHGs released in urban areas. The findings showed that in 2015 the total UCF was equal to 288 ktCO_2, specifically deriving from electricity and natural gas consumption. Moreover, Residential, Industry and Tertiary are the most carbon-intensive economic sectors. The RCF was equal to 0.30; the city emission levels were lower than the national average. Therefore, the municipality represents a typical "net-consumer" community, dominated by homes with territorial emissions due to consumption and characterized by a low number of industries and an average income per capita that is 50% lower than the national one.

Starting from these results, the study proposed an urban action plan according to the EU mitigation and adaptation policies. This plan could help the local government improve its environmental sustainability, even if more public city-level data is required for a more comprehensive analysis. Finally, it would be more appropriate for all actions to be aligned under a unique policy process to seize the opportunity to link the various local intervention policies from different fields, taking into account their existing funding, tools, processes, and resources. Capitalizing on the adaptation/mitigation connection will allow municipalities to leverage their climate change action efforts and accelerate progress toward their climate and energy goals.

1. Introduction

All cities are characterized by environmental sustainability issues, including traffic congestion, noise, air quality and GHG emissions; therefore, over the years, a number of international and European strategies and policies have been addressed to resolve these problems and, specifically, to reduce CO_2, thus affecting climate change.

In this context, the EU plays an important role toward the decrease of all these environmental impacts that represent serious threats to the quality of life of about 75% of its residents (EEA, 2017).

The EU has recognized the essential role of the cities and others local authorities for the implementation of climate change policies through the international and regional cooperation and the support of GHG reduction actions (European Commission, 2016).

The EU launched specific programs to finance actions on these themes, such as the Covenant of Mayors (CoM) initiative. Launched in 2008, CoM is addressed to European local authorities for reducing the urban GHG emissions by 20% by 2020 through specific mitigation action plans. Lastly, in 2014, the Mayors Adapt, a parallel program of CoM, was aimed at taking adaptation actions to prevent or minimize the damage caused by extreme weather events and, in the long run, by climate change. The integration of adaptation into mitigation and planning policies can offer new chances for the EU municipalities and policy-makers to improve the city environmental quality. Since 2017, this program was completely included

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Abbreviations

BEI	Baseline Emissions Inventory
CoM	Covenant of Mayors
ETS	Emission Trading Scheme
GDP	Gross Domestic Product
GHGs	Greenhouse Gases
GPC	Global Protocol for Community scale
GPP	Green Public Procurement
GWP100	Global Warming Potential
IPCC	Intergovernmental Panel on Climate Change
LPG	Liquid Petroleum Gas
NUTS	Nomenclature of the Territorial Units for Statistics
PAS 2070	Publicly Available Specification
RCF	Relative Carbon Footprint
UCF	Urban Carbon Footprint
UNFCCC	United Nations Framework Convention on Climate Change
VKT	Vehicle Kilometers Travelled
WRI	World Resource Institute

in the CoM for Climate and Energy (Covenant of Mayors for Climate and Energy, 2017; Geneletti and Zardo, 2016).

It is very important to stress that mitigation and adaptation concepts present two different goals and policies for coping with the impacts of climate change. Mitigation refers to all actions aimed at reducing GHGs at the global level to stabilize their concentration in the atmosphere in order to limit the temperature increase within the "sustainable" limit (2 °C). According to the Intergovernmental Panel on Climate Change (IPCC) report, there are currently different mitigation technologies and practices applicable in different sectors: energy production, transport, construction, industry, agriculture, forestry and waste management (IPCC, 2014). Conversely, adaptation is a novel issue and combines actions at a local level from different stakeholders and comes in different forms: planning, implementing and supporting. It involves all levels of decision-making, as well as most sectors and even the surrounding areas, bringing together actors with different knowledge, interests and values. Specifically, it refers to the response of natural or human systems to current or future vulnerabilities due to climate change and their effects. On one hand, this allows the containment of potential damage; on the other hand, this allows taking advantage of opportunities. Therefore, it includes all the preventive measures put in place to reduce the impacts associated with current and unavoidable climate change (Pietrapertosa et al., 2018; European Commission, 2013). The approach can offer new chances for EU municipalities and policy-makers to improve the environmental quality in cities. The reinforcement of market operator participation lays the foundation for effective cooperation among citizens and public administration (EEA, 2016; Covenant of Mayors for Climate and Energy, 2017).

However, although mitigation and adaptation policies are often perceived and undertaken separately, they can be realized and implemented in only one action. For instance, urban forestation, which is used to contribute to carbon absorption and GHG emission reduction, can also be strategically implemented to improve natural drainage and reduce the likelihood of flooding within the city boundaries. Thus, combined mitigation and adaptation action has the potential to multiply the benefits in a territory.

In this context, it is always very important to find a tool for assessing the environmental sustainability of a municipality in order to implement these initiatives at a local level. Additionally, it is necessary to obtain more scientific findings, practical tools, and information to support municipal governments in their task to cope with climate change, and for realizing positive outcomes from their actions in both local climate policy and the local economy (Huang Lachmann et al., 2018).

For these reasons, the UCF methodology could represent one of the most appropriate current tools that is able to identify the critical economic sectors where policy makers may intervene to implement efficiency measures to reduce environmental costs. A well-structured and properly prepared GHG emission inventory could be advantageous for various reasons: it can be the basis for implementing a risk management plan; it allows identifying interventions for GHG reduction; it can improve regulations, participation in GHG markets and adaptation of eco-friendly innovation measures; it can help engage the private sector and drive green investments that will make a city more competitive globally; it raises public awareness and establishes green city brands; and finally, a more comprehensive GHG inventory can act as a platform for cross-sector integration, planning, and decision making (D'Avignon et al., 2010; Savacool and Brown, 2010; Sandhu and Kamal, 2015; Liu and Qin, 2016; Carloni and Green, 2017).

There are currently different city-scale frameworks of GHG emissions, based on the combination of various accounting systems and inventory methods. According to Lombardi et al. (2017), it was possible to classify UCFs into two main types: namely "spatial or direct", characterized by a limited amount of data linked to the territorial GHG emissions, and "economic or life-cycle based", with inclusive information according to the accounting systems considered, including all type of releases - even those generated by export and import city activities. Furthermore, they observed that there is not yet a "global agreed-upon protocol", and so it is necessary to complete and standardize, in the short term, the accounting and reporting frameworks to compare different UCFs and to adopt shared climate strategies and actions at the global level. Some attempts have been made in this sense, such as the Publicly Available Specification (PAS, 2070), the Global Protocol for Community scale (GPC), and the Relative Carbon Footprint (RCF). Specifically, the latter is the ratio between a city's level of GHG emissions per capita and the respective national average of its host country (Da Schio and Fagerlund Brekke, 2013). It is an interesting idea to recognize cities as responsible to the national GHG emission standards or as sustainability governance models for the reduction of GHG emission, thanks to the comparison of amount of their GHG emissions with that of national counterpart. This indicator considers, indeed, all factors that affect the UCF outcome (such as city economic development, geographical conditions, social or political factors, or specific public policies linked to the national context), allowing a comparison among different UCFs (Da Schio and Fagerlund Brekke, 2013).

Based on the previous considerations, the authors aim to apply both the spatial UCF and the RCF to the Foggia's municipality (Apulia region, Southern Italy), as a case study tailored to a small Italian city (with about 150 000 inhabitants). This represents a novelty for UCF and RCF academic studies as, over the years, most research has only focused on the climate change impact assessment of megacities (Dickinson and Tenorio, 2011; Yu et al., 2012; Ala-Mantila et al., 2013; Da Schio and Fagerlund Brekke, 2013; Lin et al., 2013; Wang et al., 2013; Caro et al., 2015; Kjaer et al., 2015; Kennedy et al., 2015; Wiedmann et al., 2016; Dahal and Niemelä, 2017; Carloni and Green, 2017).

This analysis will allow the authors to individuate the most critical economic sectors of the municipality in terms of GHG emissions, specifically with regards to CO_2 because it represents 90% of the total GHGs released in urban areas. Furthermore, the authors will be able to suggest possible actions for reducing these

Fig. 1. Localization of Foggia's municipality.
(Source: our elaboration)

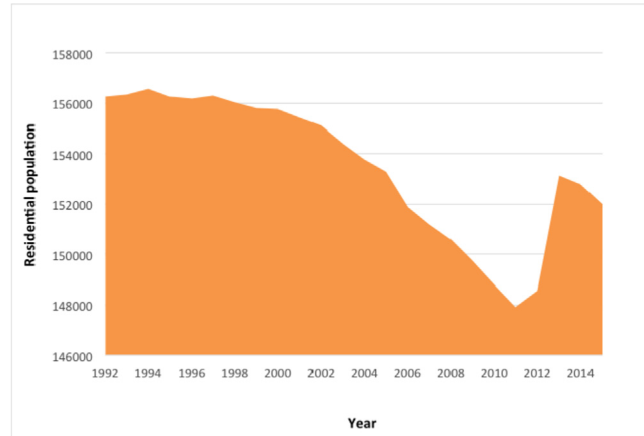

Fig. 2. Residential population time series of Foggia's municipality.
(Source: our elaboration).

emissions and for developing preventative measures to decrease climate change impacts. In this way, it could be possible to provide information to municipal governments to assist them in defining a sustainable urban environmental policy (Lombardi et al., 2014, 2016).

2. Description of Foggia's municipality

Foggia is a small city located in the flatlands of the Apulia region of Italy known as "Tavoliere delle Puglie". It is the administrative capital of a vast province (NUTS 3) with 60 municipalities, representing the third Italian province for territorial extension. This urban area lies at 15°33′6 east longitude and 41°27′30 north latitude (IPRES, 2014a), and it is recognized to be in an average seismic zone, the indicator of which is equal to 33.79 (IPRES, 2014b). This municipality has a predominantly Mediterranean climate (zone – D[1]), with an average temperature of 15.8 °C (Climate-data.org, 2018), with dry summers and low rainfall, and it covers an area of 509.26 km^2 with a total population of 151 991 (59 447 households) in 2015 (ISTAT, 2015) (Figs. 1 and 2).

As shown in Fig. 2, the demographic time series (1991–2015) was characterized by a negative trend until 2011, mainly due to the resident migrant flow toward more productive areas, such as Northern Italy and central Europe. This phenomenon was very strong after the world financial crisis, which broke in 2008. It was after 2012 that the residential population rose thanks to the presence of foreign immigrants, who constituted the workforce of the agricultural sector. Then, a rapid reduction was recorded between 2014 and 2015, likely due to scarce local economic activities (ISTAT, 2017).

Agriculture has always represented an important economic driver that contributes to the municipality's development. Public interventions in irrigation, indeed, allowed the territory to be improved by promoting this sector during the 1930s and 1940s, bringing water to the surface through the excavation of artesian wells. This technological innovation favored the cultivation of different crops and the reduction of monocultures, such as grain (Nicoletti et al., 2005; Provincia di Foggia, 2017). Later, the city economy went toward a transition phase: in the 1960s and 1970s, a strong industrialization of agricultural production occurred (such as sucrose production from sugar beets). As a matter of fact, in recent decades there was the development of manufacturing agro-food firms for horticulture (mainly tomatoes), contributing to an increase in the total number of enterprises in the province of Foggia. This increase, equal to 14 046 in 2015, was focused mainly on the *Tertiary* sector, i.e., wholesale and retail businesses and services for people and enterprises (54.7% of the total), followed by *Agriculture* (19.5%), *Industry* (17.0%) - above all buildings - and *Others* (8.8%) (CCIAA, 2015a, 2015b). Consequently, Foggia can be defined as a typical "net-consumer" community (Lombardi et al., 2017), dominated by homes with territorial emissions due to consumption and characterized by a low number of industries and low incomes on average.

3. Methodology

As mentioned above, the authors have decided to calculate a spatial UCF for this case study, A spatial UCF is characterized by the combination of the *territorial accounting system*, which defines the spatial boundary where GHG emissions occur, and the community typology, which is the main city economic structure considered, with the *Intergovernmental Panel on Climate Change* (IPCC) *inventory method* (a model to collect data). As reported by Lombardi et al., 2017, the spatial UCF represents the basic model, as it measures only the in-boundary GHG emissions, excluding all the others. This choice was necessary due to the great difficulty of receiving information from the local utilities and, consequently, gathering data. The lack of a local well-organized database for each economic sector has limited the possibility of conducting a more comprehensive analysis.

Specifically, the *territorial accounting system* allows quantifying the GHGs released only within a specific geographical area or jurisdiction's boundaries of a country (EEA, 2013), including scope 1 and scope 2 emission typologies, as established by World Resource Institute (WRI) et al., in 2014. Consequently, it does not reflect city-scale emissions from national and international trade, confining the

[1] The classification as Zone – D is relative to the period of time (from the 1st of November to 15th of April of each year) when it is possible to turn the heating system on, according to the table established by the Italian Decree no. 412 of 26 August 1993 (Presidente della Repubblica Italiana, 1993).

calculation of the GHG emissions to economic activities (production) by resident companies, municipal administration and household consumptions within the urban boundary. Moreover, the *territorial accounting system* considers city typology as the net-producer community, referring mainly to industrial or resort communities with higher territorial emissions due to the local production (Lombardi et al., 2017). In this specific case study, the inclusion of indirect emissions due to heating, cooling, electricity, and transport fuel production consumed within the geopolitical boundaries are considered.

The *IPCC inventory method* requires only the reporting of direct emissions from sectors and subsectors and can be applied at a city level within its boundaries, regardless of where the output of the production is consumed. IPCC was the first method adapted for city-scale GHG inventories and so, it is frequently used (IPCC, 2006) and combined with the territorial accounting system.

The authors intended to focus only on CO_2 emissions in 2015 (tCO_2/year), because these represent 90% of the total GHGs released in the urban area associated with main energy consumer economic sectors, both private and public, within the urban boundary. This choice is also due to the lack of a local well-organized database for each economic sector, which limited the possibility to take into account the other GHGs and so to conduct a more comprehensive analysis.

Additionally, to be able to calculate also the Relative Carbon Footprint (RCF; the ratio between the city's CO_2 emission level per capita and the corresponding national average level), the authors also estimated this value per capita. Hence, it will be possible to add another interesting result derived from the comparison with country value to measure the potential improvement toward a low-carbon urban model, considering the differences observed (Da Schio and Fagerlund Brekke, 2013).

Fig. 3 shows the pathway used to choose the typology of data necessary for the estimation of the spatial UFC and RCF.

Hence, the considered sectors were: residential (heating/cooling systems and lighting for buildings), tertiary (heating/cooling systems and lighting for buildings and equipment/facilities), municipal administration (public highlighting, heating/cooling systems, and lighting for buildings and equipment/facilities), and partially non-Emission Trading Scheme (ETS) industry (heating/cooling systems, lighting, and electrical motor consumption) and transport (public and private road mobility in the urban area).

The main considered energy vectors, instead, were electricity, natural gas, and fuels for transportation. The baseline year, chosen for the data collection, was 2015 due to a more complete and available dataset.

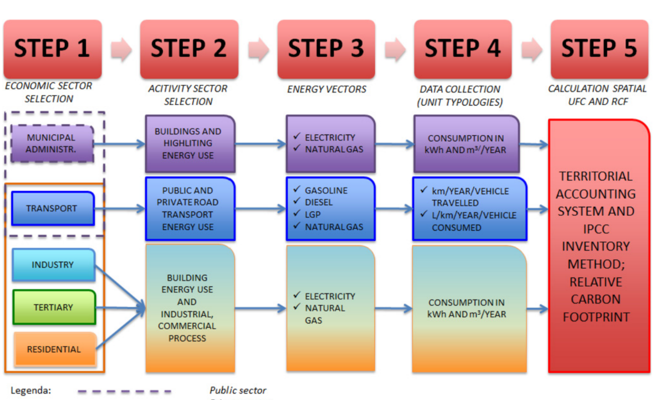

Fig. 3. Process of data analysis.
(Source: our elaboration).

3.1. Formula for GHG emission inventory

In order to calculate the CO_2 emissions, according to the spatial UFC model, the consumption of each energy vector for every selected economic sector, expressed in physical units, was considered. Calculation of the spatial UCF associated with urban activities (tCO_2/year) was performed by applying following equation:

$$UCF_{municipality} = GHG_{electricity} + GHG_{natural\ gas} + GHG_{road\ transport\ fuels} \tag{1}$$

According to the UCF methodology, each GHG emission has to be expressed according to its Global Warming Potential (GWP_{100}). In this case study, as already stressed, the authors decided to assess only the CO_2 release. Consequently, since its GWP_{100} is equal to 1, the UCF results will be the same in term of quantity and will be expressed in CO_2.

The application of equation (1) was performed by considering specific formulas, as reported by Kennedy et al. (2010). In particular:

$$GHG_{electricity} = C_{electricity}{}^{*}L^{*}I_{electricity} \tag{2}$$

where:

- $GHG_{electricity}$ is the CO_2 emissions derived from electricity consumption of all economic sectors (tCO_2/year);
- $C_{electricity}$ is consumption of electricity of all sectors (MWh/year);
- L is the line loss factor (%; Table 1);
- $I_{electricity}$ is the emission factor (tCO_2/MWh).

$$GHG_{natural\ gas} = C_{natural\ gas}{}^{*}I_{natural\ gas} \tag{3}$$

where:

- $GHG_{natural\ gas}$ is the GHG emissions derived from the natural gas consumption for heating all economic sectors (tCO_2/year);
- $C_{natural\ gas}$ is consumption of natural gas (MWh/year);
- I_{fuel} is its emission factor (tCO_2/MWh; Table 1).

$$GHG_{transport} = \sum_{road\ transport\ fuel} C_{fuels}{}^{*}I_{fuels} \tag{4}$$

where, as reported by European Union, 2010:

$$C_{fuels} = \text{mileage} \times \text{average consumption x conversion factor} \tag{4a}$$

where:

- $GHG_{transport}$ is the GHG emissions derived from road transport (tCO_2/year);
- C_{fuels} is the consumption of different fuel typologies (kWh). The main transportation fuels considered were gasoline, diesel, LPG, and natural gas.
- I_{fuels} is the emission factor for each fuel (tCO_2/MWh) (Table 1);
- mileage is the yearly average kilometers traveled by each vehicle, according to the type of used fuel (km; Table 2);
- average consumption is the fuel efficiency value (L/km; Table 2);
- conversion factor (kWh/L; Table 2).

The considered vehicles were all used for public and private urban transportation, including a municipal fleet, public transportation for passengers (buses) and individual traffic (passenger cars, motorcycles, light and heavy duty vehicles for commercial transport)"

3.1.1. Relative Carbon Footprint – RCF

In order to calculate the RCF, the authors adopted the following formula, according to Da Schio and Fagerlund Brekke (2013):

$$RCF_{municipality} = GHG_{city\ per\ capita}/GHG_{country\ per\ capita} \quad (5)$$

where:

$$GHG_{city\ per\ capita} = UCF_{municipality}/Inhabitants_{(2015)}$$

where:

- $RCF_{municipality}$ represents the Relative Carbon Footprint of Foggia's municipality. If RCF >1, municipality presents higher levels of GHG emissions than the national average of its country; on the contrary, if RCF <1, the emission levels are lower;
- $GHG_{city\ per\ capita}$ is the GHG releases of each Foggia's inhabitant (CO_2) and is related to energy use in all economic sectors;
- Inhabitants are Foggia's population in the year 2015.
- $GHG_{country\ per\ capita}$ is the CO_2 releases of each inhabitant at national level and is related to energy use (electricity and fuels; CO_2). This value was obtained by the ratio of Italian CO_2 releases (384 285 $MtCO_2$) and the total Italian population (60 665 551 inhabitants) in 2015 (ISPRA, 2017; ISTAT, 2015). Consequently, the Italian CO_2 per capita was equal to 6.3 tCO_2.

3.2. Data collection

To collect data, in some cases, the authors directly contacted the market operators (for electricity and natural gas) or, in other cases, they used national official references (the number of vehicles for transport).

Specifically, E-distribuzione SpA (2017) provided the electricity statistics for consumer typology, considering its use in private buildings, commercial and industrial activities, and public highlighting. The Municipal Administration of Foggia furnished, instead, the quantity of electricity for public buildings (Comune di Foggia, 2016).

AMGAS SpA (2017) provided the natural gas consumption for both private and public sectors for heating buildings/water and for industrial processes.

ACI (2015) reported yearly the vehicle fleet data at different geographical levels, from national to city scale. The authors decided to consider only the most used urban vehicles employed for private use in Foggia's municipality for 2015. They are constituted mainly of passenger cars (82%), motorcycles (7.78%), and light - and heavy - duty vehicles[2] for commercial transport (7.17%), representing 98 147 vehicles out of 101 233. Finally, concerning the municipal administration (public transport), they decided to consider the entire vehicle's fleet, including the urban bus category. This represents a very small quantity, equal to 29 vehicles, which belong to the ATAF SpA, a company held in part by municipal administration (ATAF SpA, 2017).

In order to calculate the consumption fuels (equation (4a)) for each fuel typology and vehicle category, the authors needed other data, as already described in section 3.1. ISPRA (2015) provided, indeed, the yearly average value kilometers traveled (vehic*km) by each vehicle per fuel typology at the national level. Instead, Ntziachristos and Boulter (2017) furnished the fuel efficiency value for typology (g/km), while the MIT Energy Club (2007) provided the density and heat calorific values of fuels (g/L and MJ/L, respectively). Therefore, the authors were able to calculate the conversion factor in kWh/L, considering that 1 kWh = 3.6 MJ (Table 2).

[2] Actually, they took into account only the light duty vehicles (i.e., with up to 3.5 t of mass) because both they circulate more than heavy - duty vehicles do in the urban boundary and represent the major quantity (equal to 5.55% of the total vehicles).

4. Results and discussion

This section presents the results in relation to the aims of the study: 1) CO_2 emissions according to the spatial UFC model; 2) RCF of the municipality in respect to the national CO_2 emissions per capita; 3) and the individuation of some mitigation interventions to reduce CO_2 emissions, and some adaptation-preventing measures to decrease the climate change impacts.

According to the spatial UFC, the total energy consumption per sector and vector (10^3 MWh) and the associated CO_2 emissions for Foggia's municipality are reported in Figs. 4 and 5.

As showed in Fig. 5, the total spatial UFC in 2015 was equal to 288 $ktCO_2$, which corresponds to 1.9 tCO_2 per capita.

In 2015, the total amount of CO_2 emissions from electricity was 160 $ktCO_2$, followed by natural gas with 84 $ktCO_2$. The most carbon intensive sectors were: a) Residential with 102 $ktCO_2$, due to the typical consumer model characterized by the use of private boilers for heating buildings and water; b) Industry and Tertiary with 66 and 64 $ktCO_2$, respectively. This means that the UCF of Foggia is mostly derived by consumption activities rather than by than production ones. Obviously, the Municipal Administration presented a lower environmental impact (12 $ktCO_2$) since it manages a smaller amount of city consumption, even if it is the responsible party and the controller of Foggia's economic activities and is designated to issue regulations for CO_2 reduction in each sector.

Finally, the total amount of CO_2 emissions from road transport fuels was equal to 44 $ktCO_2$. Concerning transportation, the passenger cars, fueled by both gasoline and diesel, were principally responsible for CO_2 emissions (26 $ktCO_2$) and represented 60% of the total. This is always due to the consumer model that induces the citizens to have and use more than one car per household (83 015 cars vs. 59 447 households).

These results are similar to some scientific studies carried out in Italy, but they were conducted on smaller urban areas than Foggia. For example, Martire et al. (2018) stressed that the biggest contribution to GHG emissions comes from the consumption of natural gas and electricity by the household sector.

Considering the Italian GHG emissions per capita (as tCO_2), for the same economic sectors considered for the case study, $RCF_{municipality}$ was equal to 0.30 in 2015. Consequently, because RCF <1, the city's emission levels were lower than its national counterparts. The motivation is given by the different profile and range of economic activities of Foggia compared with the country.

Indeed, Foggia is characterized, as already mentioned, by a low number of industrial activities and by a high-energy demand linked to the residential sector; the typical city economic structure is defined as net-consumer (Lombardi et al., 2017). Its economic development level, expressed as income per capita, in 2015 was equal to 17 384 Euro compared to an average Italian value of 20 690 Euro and to the 21 405 Euro average of cities with 100–250 thousand of inhabitants (MEF, 2017). This highlights the minor wealth that surely influences the introduction of energy strategies that are more eco-friendly and that require initial important investments. Thanks to the RCF, this can help to clarify the CO_2 emission differences with the national value, and it is possible to measure the potential improvement of a city toward a low-carbon urban model that is more oriented to sustainable development, given its economic and geographical preconditions and the national political context in which it is embedded.

Table 1
Emission factors for each energy vector.

Energy vectors	Emission factor in tCO_2/MWh	Source
Electricity[a]	0.315	TERNA SpA, 2016; ISPRA, 2015
Gasoline	0.249	IPCC, 2006
Diesel	0.267	IPCC, 2006
LPG (Liquid Petroleum Gas)	0.231	IPCC, 2006
Natural Gas	0.202	IPCC, 2006

(Source: our elaboration).
[a] Line loss factor = 6.2%.

Table 2
Components of fuel consumption formula.

Fuel typology	Vehicle category	Nr. Vehicles (2015)[a]	Average value of VKT[f] (vehic*km/year)[b]	Fuel efficiency (L/km)[c]	Conversion factor (kWh/L)
	Light Duty Vehicle	7871	3342	0.134	
	Motorcycle	265	2466	0.047	
Diesel	Passenger car	42 962	1773	0,072	9.9
	Light Duty Vehicle	5357	3952	0.096	
	Urban Bus[d]	22	25 784	0.398	
LPG	Passenger car	3488[e]	3894	0.106	6.5
CNG	Urban Bus[d]	7	45 525	0.704	2.6
	Passenger car	2639[e]	4151	0.088	

Source:
[a] ACI, 2015;
[b] ISPRA, 2015;
[c] Ntziachristos and Boulter, 2017;
[d] ATAF SpA, 2017;
[e] Osservatorio Mobilità Sostenibile in Italia (2015).
[f] Vehicle Kilometres Travelled.

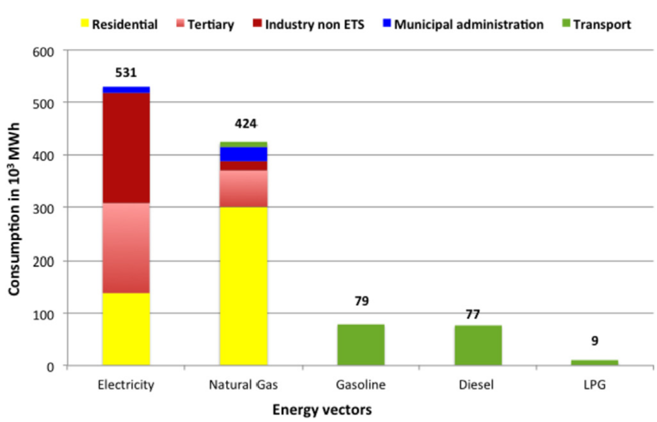

Fig. 4. Energy consumption per sector and vector in 10^3 MWh in 2015. (Source: our elaboration).

4.1. Some actions to adapt

The data inventory, along with other statistical information (demographic, income per capita, and economic structure), lays the foundation for identifying some direct and indirect actions to reduce CO_2 emissions (mitigation) and for developing preventative measures to decrease climate change impacts (adaptation) for each sector and energy vector in accordance with the public policy of the city government. The direct actions are specific technical interventions in the short term; the indirect ones are related to the energy policy planning of the municipal administration and so are propaedeutic since they are directed to increase the sensitivity and knowledge about, for example, renewable sources and energy saving in the long term.

The authors decided to focus on those situations in which public authority can be more successful overall when its policies are seated on a participatory approach, including public consultation activities. Indeed, public authority's commission is to realize actions in order to improve the quality of life of the population through mutual collaboration (Table 3).

As reported in Table 3, some actions are common among more sectors. For this reason, in order to make the discussion more functional, the authors decided to comment on the actions according to vector typology.

Concerning *electricity consumption*, for all the private economic sectors, surely campaigns on energy saving, promotion of renewable sources, regulations for building energy efficiency, updated training courses for building operators, incentives for promotion environmental management tools (EMAS and ISO 14000), and urban forestation represent the most efficient indirect actions tailored to the economic structures of Foggia's municipality. They can have both adaptation and mitigation effects. Specifically, the adoption of a Regulation for building energy efficiency could be the only solution for residential buildings. Indeed, it aims to promote the construction of buildings with superior energy - and environment - saving features according to what is established by more recent European and national laws (Directive, 2010/31/EU[3] and Italian Law n. 90 of 3 August 2013).

The campaigns to promote energy savings can also have both an adaptation and a mitigation effect. For instance, building insulation is frequently considered to be a mitigation measure to reduce energy use for heating or cooling. Nevertheless, it also often increases resilience to heat waves and/or extreme temperatures.

Urban forestation programs can primarily contribute to absorption through the photosynthesis process of CO_2 that is derived

[3] According to art. 9, Member States shall ensure that: (a) by 31 December 2020, all new buildings are nearly zero-energy buildings; and (b) after 31 December 2018, new buildings occupied and owned by public authorities are nearly zero-energy buildings.

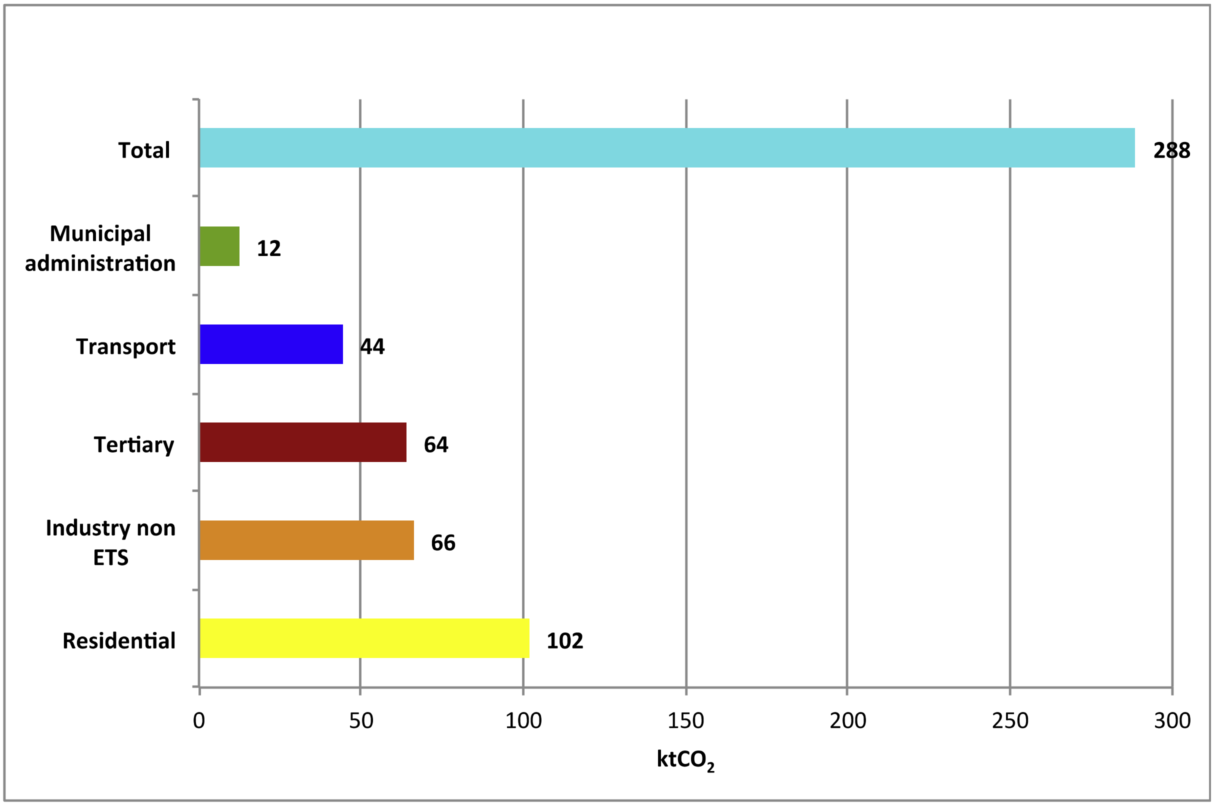

Fig. 5. CO_2 emission of Foggia's municipality per sector in $ktCO_2$.
(Source: our elaboration).

Table 3
Actions for CO_2 emission reduction for economic sectors and energy vectors.

Sectors	Energy vectors	Actions	Direct	Indirect	Adaptation	Mitigation
Residential	Electricity	Energy efficiency of building with photovoltaic systems on roofs	X			X
		Regulation for energy efficiency of buildings		X	X	X
		Update training course for building operators		X	X	X
		Campaign on energy saving and promotion of renewable energies		X	X	X
		Urban forestation[a]		X	X	X
	Natural Gas	Energy-efficient heating systems (solar panels on roofs for heating water; replacing boilers; thermal insulation sides; painting, waterproofing and repaving, etc.)	X		X	X
Tertiary	Electricity	Incentives for promotion of the environmental management tools (EMAS and ISO 14000)		X		X
		Campaign on energy saving and promotion of renewable energies		X	X	X
	Natural Gas	Incentives for promotion of the environmental management tools (EMAS and ISO 14000)		X		X
		Replacing boilers more efficient or fed by biofuels	X			X
Industry	Electricity	Incentives for promotion of the environmental management tools (EMAS and ISO 14000)		X		X
		Campaign for energy saving and promotion of renewable energies		X	X	X
	Natural Gas	Incentives for promotion of the environmental management tools (EMAS and ISO 14000)		X		X
		Replacing boilers more efficient or fed by biofuels	X			X
Municipal administration	Electricity	Energy efficiency of building with photovoltaic systems on roofs	X	X	X	X
		Substitution of high pressure sodium light bulbs with LED lighting	X			X
		Urban forestation[a]		X	X	X
		Green Public Procurement		X	X	X
	Natural Gas	Energy efficiency of building (solar panels on roofs for heating water; replacing boilers; thermal insulation sides; painting, waterproofing and repaving, etc.)	X		X	X
Transport	Fuels	Municipal Administration				
		Replacement of old vehicle fleet	X			X
		Replacement of eco-friendly tires,	X			X
		Enhancement of wireless networks		X	X	X
		Residential				
		Promotion and implementation of smart or sustainable mobility		X		X
		Cycle-pedestrian route	X		X	X
		Bike sharing service	X			X
		Enhanced public transport	X			X

(Source: our elaboration).
[a] Not confined only to Electricity but also to the other vectors and sectors.

from the combustion of fossil fuels for energy production and consumption (indirect mitigation action). Therefore, it affects all vectors (natural gas and transport fuel), as reported in the footnote of Table 3. Furthermore, it can also be strategically used as an adaption tool for the private sectors, since: a) it can improve natural drainage of urban soil, b) it improves air quality, and c) it provides shade for residential buildings and reduces the use of cooling systems.

Some direct actions include photovoltaic systems on roofs (considering the favorable climate of Foggia, which has a high yearly solar irradiation [1550 kWh/m^2 in 2016]; GSE, 2017) and energy -saving devices including heating equipment, appliances, lighting, energy intensity meters, and building materials. Renovated buildings, besides reducing energy consumption in the long term (mitigation), if they present shading structures, could reduce the heat flux of buildings and further improve thermal comfort (adaptation).

For the municipal administration, the substitution of high-pressure sodium light bulbs with Light Emitting Diode (LED) lighting and the energy efficiency of buildings with photovoltaic systems on roofs (already applied to some public schools in 2006) are the direct actions. The former, indeed, was approved by the Municipal Council on 22 December 2015 with the adoption of the Plan for Public Highlighting. Among the indirect actions are the Green Public Procurement (GPP) and the urban forestation. The former is regulated by the National Procurement Agency, called "Consip." Indeed, in Italy, all public authorities are obliged to buy products and services using this system to make public financial resource use more efficient and transparent. The GPP promotes the purchase of products and services with low environmental impacts. In order to cope with the energy consumption savings, Consip launched a framework contract on "Integrated Energy Management Services" relative to heating services, including improvement of energy efficiency, consumption reduction, and CO_2 emissions avoidance (European Commission, 2012). To reach these goals, there are different mitigation specific actions, such as the installation of electronic meters and the constant monitoring for indoor temperatures of the buildings, the assessment of the optimal level of consumption for heating and energy services, and the energy audit performed for every buildings. The urban forestation effects are similar to those underlined for the private sectors.

For *natural gas demand*, the adaptation of energy - efficient heating systems, such as solar panels on roofs for heating water; new boilers; thermal insulation sides; and painting, waterproofing and repaving might represent direct actions for both residential and public sectors. Incentives for promotion of the environmental management tools (EMAS and ISO 14000), instead, are exclusively for Tertiary and Industry. This indirect intervention, through a synergistic collaboration between the market operators and public managers, promotes the implementation of these tools in view of incentives for the enterprises or industries (i.e., reduction of taxes).

Finally, to reduce *fuels for road transportation*, different interventions could be implemented, passing by the adoption of financial and executive policies to encourage the use of more environment-friendly vehicles. In residential settings, for example, even if the consumer preference for private passenger cars has overcome any other moving modes, public transport has to be encouraged as well as walking, cycling (new cycling paths could also, for instance, incorporate natural or permeable materials that improve storm water drainage, representing thus an adaptation action), and modernization of bus fleet. In the long run, campaigns to sensitize citizens toward smart and sustainable mobility have to be promoted. In the public sector, replacement of old vehicle fleets and the use of eco-friendly tires might be the best direct solution. As indirect an action, instead, the enhancement of wireless networks to reduce mobility at municipal offices is surely an interesting management policy. All these interventions for Foggia's municipality could rationalize the traffic congestion and encourage citizens to change their transport habits within the urban area.

With a low-carbon mitigation and adaptation action plan, Foggia's government should be able to harvest not only environmental opportunities but also economic ones, derived by the established EU funding. According to Huang Lachmanna et al. (2018), more studies have to be carried out to also assess the social and institutional benefits that come from the climate change adaptation plan.

Actually, there could be socio-economic benefits such as attracting investments from both higher authority and other sources to realize low-carbon buildings, improving the environmental heritage among citizens, and creating new employments to implement the specific actions.

The proposal of environmental sustainability policy for Foggia might definitely represent a track for other local governments of similar size, even if it has to be improved to become more comprehensive. Indeed, it is necessary to consider the other sectors (agriculture and waste management) that are not included in this study and to integrate them in general urban planning policies (Fujii et al., 2017).

5. Conclusions

The present study highlighted the important role of the European Union in supporting climate change mitigation and adaptation strategies by establishing specific initiatives addressed to increase the environmental sustainability of cities. The UCF can represent an important tool for measuring this environmental impact and identifying those economic sectors that are mainly responsible for the direct and indirect GHG emissions in city boundaries. This information is useful for the public authorities to elaborate a local action plan aimed at reducing these gases and at developing preventative measures to decrease climate change's impact.

In this context, this paper calculated the UCF and the RCF of Foggia, a small city in Southern Italy with about 150 000 inhabitants. This represents a novelty for academic research, since no previous study has been carried out for a municipality of the same size. The findings, which focus only on CO_2 emissions, showed that the total UCF was equal to 288 ktCO_2 in 2015. Specifically, the total amount of CO_2 emissions from electricity was 160 ktCO_2, followed by natural gas with 84 ktCO_2. The most carbon intensive sectors were Residential (102 ktCO_2), Industry (66 ktCO_2), and Tertiary (64 ktCO_2). The RCF was equal to 0.30 in 2015, and so the city's emission levels were lower than the national average. This is due to the city's different profile and range of economic activities compared with the country. Indeed, Foggia is a typical "net-consumer" community, dominated by homes with territorial emissions due to consumption and characterized by a low number of industries and an average income per capita 50% lower than the national one.

According to these results, the authors were able to identify some direct and indirect actions for each sector and energy vector in line with the public policy of Foggia's city government. The punctual identification of this action plan for Foggia, following the indication of the EU mitigation and adaptation strategies, could help the local government to improve its environmental sustainability. However, it is necessary that more public city - level data are available to allow a more comprehensive environmental analysis and that all these measures be aligned under a unique policy process. This means that Foggia's public authority has to catch the opportunity to link the various local intervention policies in different fields to take in advance their existing funding, tools,

processes, and resources. The capitalization of the adaptation/mitigation connection can allow municipalities to leverage their climate action efforts and accelerate progress toward their climate and energy goals.

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